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Using System Dynamics to Model Mobile Commerce Diffusion

Wenqing Wang[1], France Cheong[2]

School of Business Information Technology, Faculty of Business, RMIT University
Level 17, 239 Bourke Street, Melbourne, Vic 3000, Australia
[1]wenqing.wang@rmit.edu.au, [2]france.cheong@rmit.edu.au

ABSTRACT

Mobile commerce is increasingly perceived as a powerful lever to foster growth of local economy and an opportunity to generate revenue. However, both the literature and empirical evidence have revealed that there exist perils hidden in decision-making by mobile commerce advocates. A system dynamics (SD) approach is used in this article to analyze how factors will influence the process of mobile commerce diffusion. In this paper, mobile commerce market formation is studied as a social economic system, which is dynamic and whose states change continuously. The model-building process incorporates a wide variety of sources of knowledge ranging from system thinking, through international marketing and management science, to system dynamics. The resulting simulation models are developed upon the mental models of a group of experts and available information from written documents, web forum, and online workshops. A simulation model is empirically established and simulated for the Chinese market. The model development and related analysis provides a typical example in using system dynamics to understand the process of mobile commerce diffusion and decision-making.

Keywords: mobile commerce, electronic commerce, system dynamics, innovation diffusion, simulation, modeling

1. INTRODUCTION

The fact that m-commerce is developed and rooted in Western countries makes m-commerce implementations more Western-oriented. Most of the m-commerce services are created to meet the requirements of the pre-existing infrastructures and environments of developed economies. This situation will make developed markets and emerging markets totally different in evaluating the market potential. Is there a generic model that is globally applicable in simulating each of the existing developed or emerging markets? System thinking and system dynamics are relevant methods in achieving this purpose. In order to accurately reflect m-commerce market, it is necessary to put mobile commerce diffusion under system thinking [1-3], in which the mobile commerce market is regarded as a complex system and the relationship between its existing structure and the behavior will be explored in a dynamic situation. Efforts in this area are likely to help entrepreneurs in learning the mobile commerce market and understanding opportunities and pitfalls related to m-commerce decision-making.

In order to explore the mobile commerce market, we developed a system-learning framework. In the real world, there are two categories of mobile commerce markets. One is called the existing mobile commerce market, or similar market like mobile communication market, which already exists in some developed countries. The application of mobile communication service and mobile commerce service in these countries provides important empirical evidence to explore new emerging markets. Another category is the emerging mobile commerce market in developing countries. Because mobile commerce in emerging area is still in its infancy, the market is in a dynamic state. The structure is still unknown. Large-scale experiments about the system are inevitable if there is no other method available. In fact, any controlled experiments about a countrywide dynamic market may turn out to be expensive and unrealistic. Whereas developing virtual world model to simulate the real world and doing experiments on the computer-based model is more cost effective and operative. As Sterman [4] points out, a virtual world model provides low–cost experimentation for learning complex system without the limitation of time and space. This paper is aimed at introducing the modeling of the virtual world.

System thinking and system dynamics are effective tools to explore the world. Information collected from the real world will be analyzed and synthesized using system thinking [2, 5], system dynamics [6-11] and innovation diffusion theories [12, 13]. Group experts' opinion is solicited to enforce the modeling process. A model is finally developed with main feedback loops and logical and mathematical relationship coupling the key variables. Since the research is still in progress, the empirically developed model will be further tested using the data collected from existing markets. After testing, the model will be applied to other existing and emerging markets.

Our research framework is divided into the four stages: stage 1, analysis of mobile telecommunications industry, management science, control theory, computer simulation and Delphi surveys, aimed to establish theory and to build qualitative System Dynamics (SD) models; stage 2, development of a generic SD simulation model based on the insights from stage 1; stage 3, collection of several secondary data and primary data in existing market, aimed to calibrate, validate the model developed in the previous stage; stage 4, scenario analysis and corresponding strategy design in any target market.

Up to now, stages 1 to stage 2 have been finished and a SD model has been built. This article aims to outline the findings generated so far from the research. In order to provide a clear outline for the paper, the main critical loop and stock and flow analysis of m-commerce diffusion is initially outlined. Then, modeling analysis is presented. Such an analysis aims to depict the main forces controlling the flow rates associated with local policies and other participants' strategies [5-7]. Finally, the main research findings and implications for further research are summarized.

2. MODEL DEVELOPMENT

Mobile commerce diffusion can be considered as a technological innovation. The diffusion and adoption of news ideals and new products often follows S-shaped growth patterns [4]. The problem is to identify what the positive feedback that generate the initial exponential growth of a successful mobile commerce diffusion are and what the negative feed back that limits the growth are and, to what degree, any endogenous or exogenous variables will influence the growth both in magnitude and speed of reaching an equilibrium.

2.1 Main Causal Loop and Stock Flow

The system boundary of the research refers to any mobile commerce market covering a geographical country or region, in which a certain number of populations reside. The number of people in the population fluctuates with the variation of net increase rate (birth rate minus death rate), which is controlled by local population policy through adjusting birth rate. In the population pool, a proportion of the population has the Capability to use a mobile terminal (hereafter refers to mobile phone) because their income and knowledge make them eligible to consume the mobile phone service although they may have not taken the service. This part of the population is called capable population. From the capable population, some of them, who have adopted the mobile phone services, are called mobile terminal users. In the emerging mobile commerce market, the 3G licenses are not issued yet (3G refers to the third generation of telecommunication networks). It means up to now there is no actual mobile commerce user but the mobile terminal users are the potential ones. As long as there is a demand from the market, mobile terminal manufacturers will replace ordinary mobile terminals with mobile terminals with mobile commerce capability, over which commerce services will be conducted. Then the mobile terminal users will gradually consume the mobile commerce services and become actual mobile commerce users.

Figures 1 and 2 illustrate the causal loop diagram and stock flow diagram identified for the main system. To visualize it, imagine the whole market system is like a water irrigation system with the population as the source at the top; the flow starts at Potential Capable Population, passing through Potential Mobile Terminal Users, and returns back to Potential Capable Population. The process forms a typical closed causal loop. As illustrated in Figure 1, the Actual Mobile Commerce Users come from Actual Mobile Terminal Users, the Actual Mobile Terminal Users from the Actual Capable Population, and the Actual Capable Population from the population reservoir in the origin. The clockwise closed loop starting from the Potential Capable Population through the Potential Mobile Terminal Users to the Potential Mobile Commerce Users illustrates the evolution, development and formation of mobile commerce diffusion. It is along this critical process that the research starts to explore the system structure and discover the market behavior over time both in the short term and in the long term.

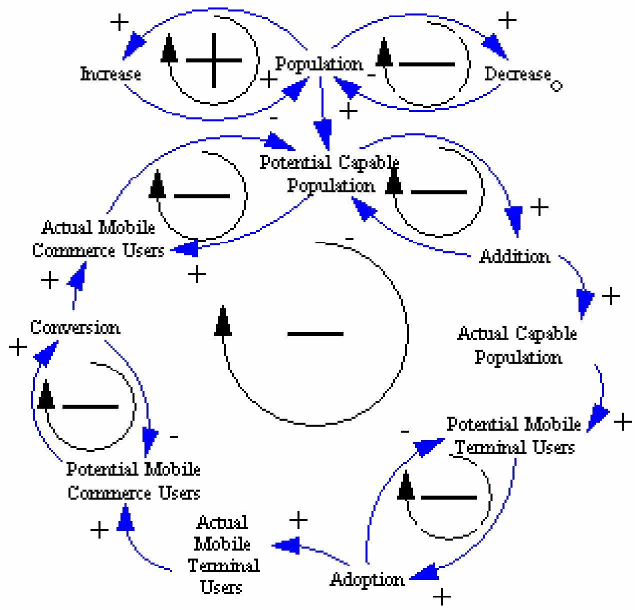

Figure 1 Causal loop diagrams in main system

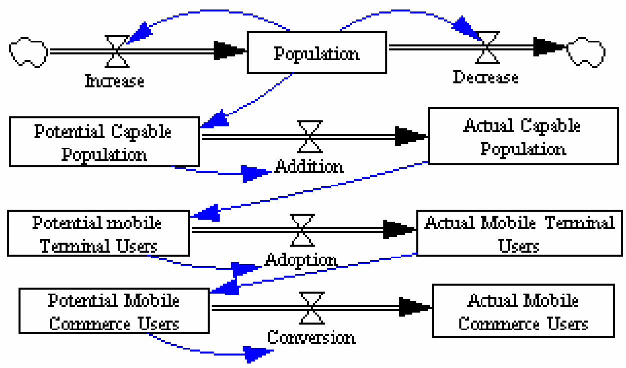

Figure 2: Stock and flow diagram in main system

The whole system includes one big closed feedback loop and four semi closed feedback loops (excluding the population loop). There are two fundamental loops that affect the number of Mobile Commerce Users. One is the clockwise loop from the Potential Capable Population through the Potential Mobile Terminal users and the Potential Mobile Commerce Users back to the Potential Capable Population. In this loop, starting from the Potential Capable Population in a clockwise direction, an increase in value of each variable will result in the increase in value of the next variable except that an increase in Actual Mobile Commerce Users will reduce the level of Potential Capable Population. Thus, the loop constitutes a negative loop (in Figure 1, B, short for balancing, is used to denote a negative loop; R, short for reinforcing, is used to indicate a positive loop). Another important loop is the semi loop directly linking the Potential Capable Population and the Actual Mobile Commerce Users. An increase of the Potential Capable Population will increase the value of the Actual Mobile Commerce Users, but, on the contrary, an increase of the Actual Mobile Commerce Users will decrease the value of the Potential Capable Population. This semi loop is also a typical negative loop. The combination of these two fundamental loops determines the state of the Actual Mobile Commerce Users. With these loops combined with variables, a variety of behavior patterns are possible [7]. In this research, the big negative loop, as well as any semi negative loop, generates flows that add to each level downstream to the Actual Mobile Commerce Users and tries to generate goal-seeking behavior. It is the goal and its development that the research tries to seek.

Another important loop (stock) that is the beginning of the main stream at the top of Figures 1 and 2 is related with the population state. The population is normally regarded as an exogenous factor and defined as a constant. In this research, the population is presumably regarded as an endogenous factor because population policy is widely manipulated as a tool to change long-term conditions in most of the populous developing countries. For example, family planning is used as a leverage to control the population birth rate. The population in the system is the only source of the Potential Capable Population, which is the starting point of the flow generated in the main loop, so the fluctuation in the population will inevitably vary the flow in the main loop.

2.2. Simulation Model

A generic model, developed using the PowerSim software package, focuses on the adoption and diffusion of mobile commerce service. The factors that influence the change rate in each level are derived from the related theory and experts' opinion. This section examines the assumptions and equations contained in each level. In the future, more field survey will be done and more current data collected to consolidate the robustness of the model. The simulation covers a time span of 50 years and takes each year as time step. Next we will explain how to formulate the relationships among factors and level and then articulate them logically and mathematically.

Population development sub model

The first sub model is the population development model. The factors that influence the level of population are shown in Figure 3. Population in the system is increased with the inflow of birth and decreased with the outflow of death and mortality. Fractional Birth Rate and Population determine the amount of Increase. The Fractional Birth Rate is further decided by the fraction of couples who are in the age of first time bearing child but never gave birth to any child before, the age at which the couple can be allowed to bear first child and the number of children that the couple can give birth to during the period of bearing age. Decrease presumably depends on the life expectancy in the country under investigation. The equations adopted in the sub model are listed as follows:

(1) Population=Increase - Decrease
(2) Increase=Fractional Birth Rate x Population
(3) Fractional Birth Rate=Fraction of First Child Bearing Age Couple x First Child Bearing Age x Number of Birth for One Couple
(4) Decrease=Population/Average Lifetime

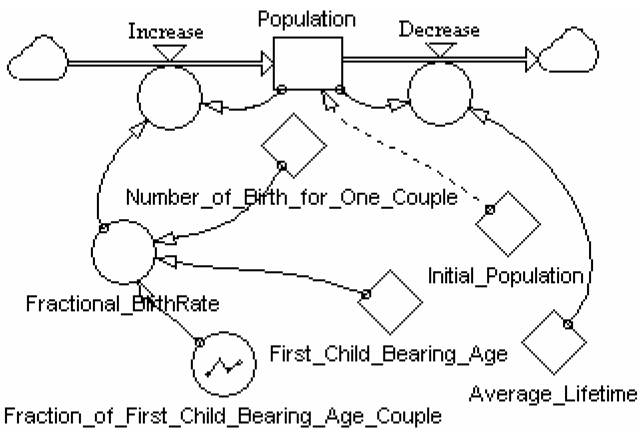

Figure 3: Population development sub model

Capable population conversion sub model

The second sub model is the model for determining the level of the capable population. The population is classified into two categories. One is the capable population which is an independent economic entity in the society and to whom mobile terminals are useful. Another part is the potential capable population who is a dependent economic entity and to whom a mobile terminal is temporarily useless. For example, young people under eighteen years old are typical potential capable population but not of the actual capable population. When they grow up they become members of the capable population. Elderly people over a certain age are presumably regarded as persons who will never use mobile terminals. Elderly people will be excluded from the initial value of the Capable Population. As depicted in Figure 4, the Historical Birth controls the addition to the Capable Population. After eighteen years, the addition to the Capable Population is the today's Increase, an 18-year delay of Increase. To simplify our simulation, we choose eighteen year as time span for the first simulation. After the first simulation, we get the data about Increase. After we feedback the data to Historical Addition, we can get another 18 year simulation. As long as the simulation is needed, theoretically, the time span for Historical Addition can extend to any time period. Analyzing the historical birth number of the previous eighteen years and directly drawing a curve between birth and year can determine the addition rate. It is easily realized through lookup functions in the simulation, which allows manually inputting the collected data or directly importing data from other applications.

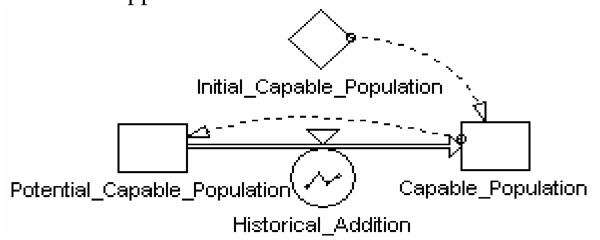

Figure 4: Capable population conversion sub model

Mobile terminal user addition sub model

The third sub model is the model for determining the level of mobile terminal users, i.e. modeling the addition of mobile terminal users in the mobile terminal market. We assume that personal income influences the addition of mobile terminal users. With the improvement of living standards brought by economy development, more and more people can afford to buy mobile terminals. Every year, a certain number of persons become actual mobile terminal users. In developing countries, there exists a great gap in the economic environment between urban and rural areas, so the addition is assumed to be different under rural and urban contexts. The concept of urbanization is introduced.

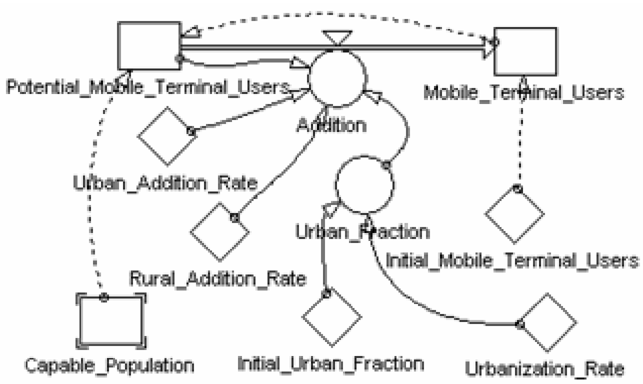

Figure 5: Mobile terminal addition sub model

As illustrated in Figure 5, Addition is determined by Rural Addition Rate, Urban Addition Rate and Urban Fraction. Urban Fraction is also a dependent variable that depends on the urbanization pace in the region. The key equations in this level are expressed as follows:

(1) Addition = (Rural Addition Rate x Rural Fraction + Urban Addition Rate x Urban Fraction) x Potential Mobile Terminal Users.

(2) Rural Fraction=1 - Urban Fraction

(3) Urban Fraction=Initial Urban Fraction x (1+Urbanization Rate).

Mobile commerce user conversion sub model

The final sub model is the model for determining the level of mobile commerce users, i.e. modeling the conversion of mobile commerce users or the diffusion of mobile commerce service in the mobile commerce market. Because mobile commerce service is a technological innovation, Bass diffusion theory [14] is applicable here.

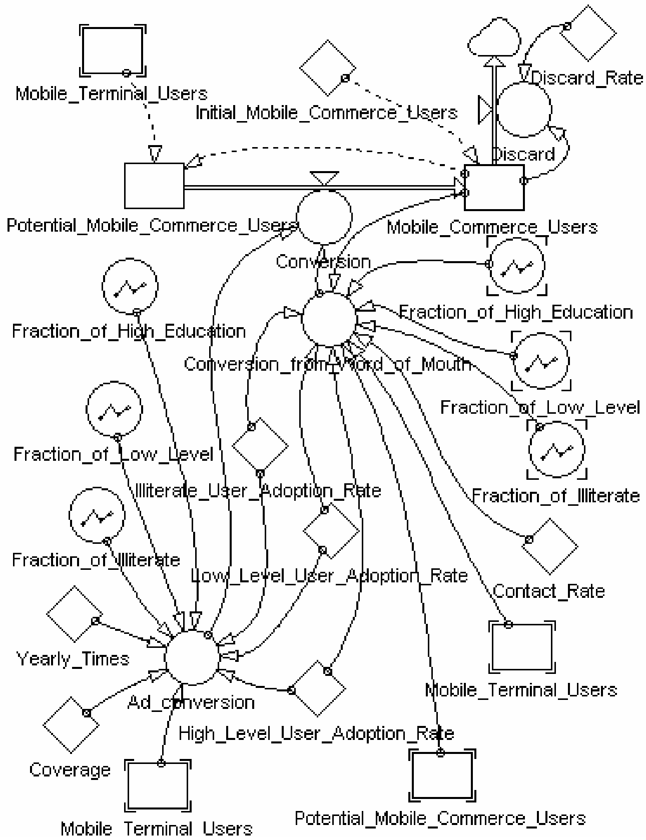

Figure 6: Mobile commerce user conversion sub model

The sub model in Figure 6 illustrates the factors that directly affect the conversion. The influences mainly come from the scale and intensity of information disseminations about mobile commerce among target users and the education level of recipients. The information propagation refers to advertising and "word of mouth". Based on the education level, mobile terminal users are classified in three groups. One is called illiterate who have received no education at all. Another one is defined as low level education users who have finished the primary or secondary or equivalent education, and the other one is called high level education users who have achieved tertiary or tertiary-above education. Because they have different education background, they take different attitudes toward mobile commerce services. Their attitudes are reflected on their adoption rate.

The equations used in the model are listed as follows:
(1) Conversion = Ad conversion + Conversion from Word of Mouth - Discard
(2) Ad conversion = (Fraction of High Education x High Level User Adoption Rate + Fraction of Low Level x Low Level User Adoption Rate + Fraction of Illiterate x Illiterate User Adoption Rate) x Mobile Terminal Users x Coverage x Yearly Times
(3) Conversion from Word of Mouth = (Fraction of High Education x High Level User Adoption Rate + Fraction of Low Level x Low Level User Adoption Rate + Fraction of Illiterate x Illiterate User Adoption Rate) x Potential Mobile Commerce Users x Mobile Commerce Users/Mobile Terminal Users
(4) Discard = Mobile Commerce Users x Discard Rate

On the aspect of advertisement, the times and coverage area is controlled by mobile commerce providers. Every advertisement covers a certain number of populations, which consists of persons with three different education backgrounds. Advertising will induce a number of potential mobile commerce users to adopt the new service and become an actual mobile commerce user. Each kind of person with specified education background has its own fraction in target population and conversion rate. The total effect from advertisement is calculated using equation (2).

Another aspect is direct contact, also called demonstration effect or “band wagon”. The process is visualized as someone in the Potential Mobile Commerce Users group being converted into an Actual Mobile Commerce Users. The two groups of people communicate and make contact with one another. When they make contact, there is some chance that the comments of the person who is a member of the Actual Mobile Commerce Users group will cause the person who is in the Potential Mobile Commerce Users group to adopt the service. The model shown in Figure 6 assumes that for each such contact between a person in the Actual Mobile Commerce Users and a person in the Potential Mobile Commerce Users there will be a number of conversions. This conversion is called conversion from word of mouth. As illustrated in equation (3), the number of conversion in a year will be equal to the sum of contributions from each category of potential mobile commerce users with different educational background. The conversion of each category user is equal to the specified adoption rate times the specified fraction in the Potential Mobile Commerce Users groups, times the product of Actual Mobile Commerce Users and Potential Mobile Commerce Use, and times the Contact Rate.

Another important outflow in this level is Discard, which is shown in Figure 6 as a sink. Because mobile commerce is still in its infancy, there inevitably exist a lot of issues such as ease of use, security, usability, technological obsolescence etc, which bring discard and reduce the level of actual mobile commerce users. As expressed in equation (4), Discard is the product of discard rate and actual mobile commerce users. In reality, the discard rate may be very high at the beginning of conversion. As time elapses, the discard rate will decrease.

Mobile commerce diffusion model

The main model can be obtained by articulating the relationships among levels. Population equals potential capable population plus actual capable population. The actual capable population is the sum of potential mobile terminal users and actual mobile terminal users. Actual mobile terminal user involves potential mobile commerce users and actual mobile commerce users. Each level in the upper stream provides information to the next level.

3. SIMULATION AND FINDINGS

We collected preliminary data for the Chinese market available from the Chinese Statistics Bureau and the United Nations database. Wherever data was not available, we used common sense to arrive at some reasonable values. The results of a simulation run of a typical scenario with a time span of 50 years are shown in Figure 7 and compared in Figure 8.

The first graph in Figure 7 shows the population level, which grows very fast in the first 10 years. The level then reaches a peak of 1.5 billions after 10 years. Afterwards it starts to decline and eventually drops down to the initial level of 1.3 billions. The second graph shows the capable population level, which grows linearly from the initial amount of 600 millions to 1 billion in 50 years time. The third graph shows the mobile terminal users level which increases from the initial amount of 200 millions to 570 millions. During this period the market of mobile terminal users displays a goal-seeking behavior to reach a goal (arbitrarily set at 570 millions in the simulation run). The fourth graph at the bottom shows the level of conversion of potential mobile commerce users to actual mobile commerce users. This follows a quasi S-shaped pattern. In the first 30 years, the number of actual mobile commerce users will reach a maximum of 200 millions. The whole process will experience three stages. The first stage (market introduction) starts at the beginning of the simulation period and ends where the curve starts to take off. During this phase, which lasts for 15 years, development is slow as the number of actual mobile commerce users is less than 30 millions. The second stage (market growth) covers the period from the time the exponential development starts to the time it starts to level off. This phase lasts for another 15 years. In this phase, the number of actual mobile commerce users skyrockets from an initial amount of 30 millions to 200 millions at the end. The increase is initially exponential and then changes to a goal-seeking pattern. In the final stage (market maturity), the dynamic market, after booming in stage two, reaches a new equilibrium. The amount of actual mobile commerce users is stabilized and remains at a high level.

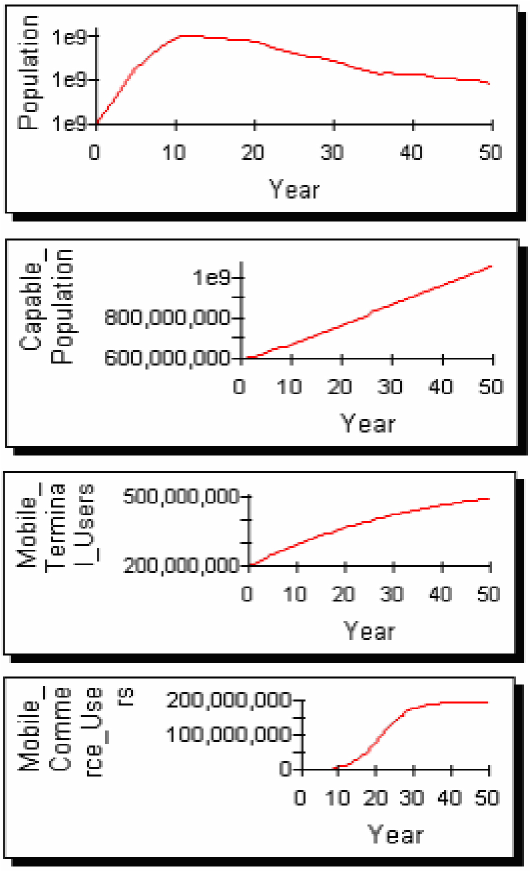

Figure 7: Key levels change in the system

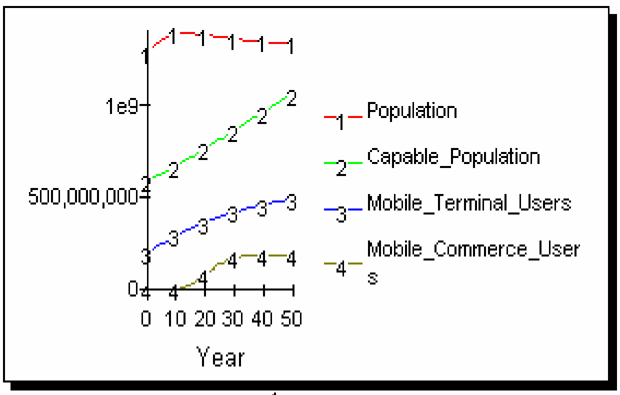

Figure 8: Contrast of the key level development in China

4. CONCLUSION

We have proposed a system dynamics model of mobile commerce diffusion and used preliminary data from the Chinese market to perform some simulation runs. Our intention is not to forecast the number of mobile commerce users in the future. Rather, our purpose is to discover the factors that influence the development of mobile commerce and their inter-relationships. This will undoubtedly help in decision-making processes such as exploring the effects of different policies and strategies to achieve certain goals (e.g. a targeted number of users, etc) under different scenarios. The model is still under development and we need to collect more data from the Chinese market (telephone interview, questionnaire survey, etc.) to improve it. We are also considering conducting a Delphi survey for the purpose of validating the model. Experts will be recruited from China and their feedback on the model sought.

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